ARKIV FÖR FYSIK Band 2 nr 26

Communicated 7 December 1949 by AXEL E. LINDH and HARALD NORINDER

A 200-kV neutron generator, I

By GÖSTA CARLSON

With 8 figures in the text.

At the Institute of Physics at Upsala a neutron generator[1] has been constructed under the supervision of Professor A. E. LINDH. The neutron generator was designed for the D (d, n) reaction

$${}_1D^2 + {}_1D^2 = {}_2He^3 + {}_0n^1$$

due to the superior neutron output of this nuclear reaction at the high tensions in question in comparison with other reactions possible.[2] The ion source is of the low-voltage arc type, and is supplied with deuterium gas from a gas reservoir; the target consists of ice of heavy water, strongly cooled down with liquid air. Experiments have also been made with another target which requires less strong cooling, viz. heavy water and phosphorus pentoxide. A disadvantage is the inferior neutron output which one then obtains. The acceleration tube, which is supplied with a separating magnet, yields a good monokinetic ion beam.

A considerable improvement in the construction, in comparison with other similar apparatus[3], has been carried out on Professor LINDH's suggestion. The transformers and rectifiers as well as the A. C. generator belonging to them, which are needed for running the ion source, have been stationed in a separate corona shield on an insulator at the side of the acceleration tube. The arrangement is seen in Fig. 1. By this new construction a decided advantage is gained as to the greater accessibility to the ion source by the necessary adjustments and, in general, a more simple managing of the apparatus.

The ion source

Two different kinds of ion sources of a low-voltage arc type have been used. One of the ion sources[4], reproduced in Fig. 2, is constructed with a straight capillary of a length of 20 mm and a diameter of 3 mm. The gas is supplied through an accurate adjustable needle valve, which opens out into the middle of the capillary. The gas consumption is about 15 µl/ sec. at atmospheric pressure, measured through readings on the manometer of the gas reservoir. The ion current emanates through a diffusion hole with a diameter of 1.7 mm and a length of 5 mm. The hole is situated in the middle of the capillary. The ion beam is prefocused with an electrostatic lens. The voltages to the lens electrodes are variable within 0–20 kV and 0–15 kV, resp. The brass block as well as the anode and the cathode are cooled with circulating oil, which comes from an oil-pump on the earth side. The oil passes through a copper spiral tube, which is cooled by water, then through a pressure-stabilizing oil reservoir and is circulated through the system by a gear pump. The same oil, which cools the ion source, is also used for cooling the high-ohmic resistance.

---

[1] G. CARLSON, Ark. f. Mat. Astr. o. Fysik, Bd 34 A, N:o 29.

[2] AMALDI, HAFSTAD and TUVE, Phys. Rev 51, 896 (1937).

[3] S. EKLUND, Ark. f. Mat. Astr. o. Fysik, Bd 29 A, N:o 7, and Bd 33 A, N:o 14.

[4] J. KOCH, Massespektrografisk isotopadskillelse, Diss. Kbhvn 1942.

The other ion source, Fig. 3, is constructed according to ZINN[1,2]. The anode is fixed insulated to a disc of perspex, and is cooled by oil. The filament, a 0.25 mm tungsten wire, is supported by four sparking plugs and located around the conical steel diaphragm. The distance between the top of the cone and the exit hole is adjustable from 0–3 mm. For this purpose the cone is supplied with set-screws. The exit hole is bored in an exchangeable disc so as to make it possible to investigate various shapes and diameters of this hole. Satisfactory results have been obtained with a conical borehole that has a diameter of 7 mm at the top and 1.5 mm at the bottom. The distance between probe and plate was generally 0.7 mm. This distance is variable, the probe being screwed in the carrying insulator of Mycalex. The central canal in the probe is 1 mm in diameter and 6 mm long. The different parts of the ion source are mechanically centered with great precision. The cooling of this ion source is brought about by the cooling oil passing through a copper spiral tube, which is soldered at the copper cylinder forming the body of the ion source. This copper winding is omitted in Fig. 3. The cathode, which is made of four sparking plugs, is not cooled by oil.

Fig. 4 is a coupling scheme of the electrical equipment for running the ion source. From the figure it is clear what the parts are which, in the special corona shield, are separated from the corona shield where the ion source and the gas container are situated. Connected with the ion source is a voltmeter consisting of a mA-meter in series with a resistance of 20.3 MΩ. This instrument measures the energy (at maximum 20 keV) the ions possess before being accelerated by the high voltage. However, there is a certain energy spread depending on where the ions are formed in the field from the probe. A control instrument of a maximum of 10 mA, which records the current flowing to the probe, connects the latter with the high tension output of 15 kV.

In the other corona shield there is a filament transformer with a variable output of 4–10 volt, which delivers the current to the filament in the ion source. Within its oil-tank are also the transformer and rectifier aggregate which yield a max. of 250 V. and 2 A. These are intended for the arc current. A series resistance, R_3, variable between 30 and 400 Ω, is adjusted to such a value that the arc is stable. Another oil-tank is constructed for the two high-voltage transformers and rectifier tubes producing the voltage for the focusing lens. One of these voltages is variable from —20 kV to +20 kV, the other from —5 kV to +5 kV. They are connected in such a way as to give maximum outputs of +20 kV and +15 kV, resp. These voltages are connected via the two limiting resistances R_4 and R_5 to the wall of the ion source and the probe, resp. The third electrode in the prefocusing system is connected with the corona shield. The two rectifier sets are made extremely compact, the insulation corresponding to 25 kV against earth. In order to adjust the primary voltages

---

[1] W. H. ZINN, Phys. Rev. 52, 655 (1937).

[2] Th. JORGENSEN Jr, R. S. I. 19, 28 (1948).

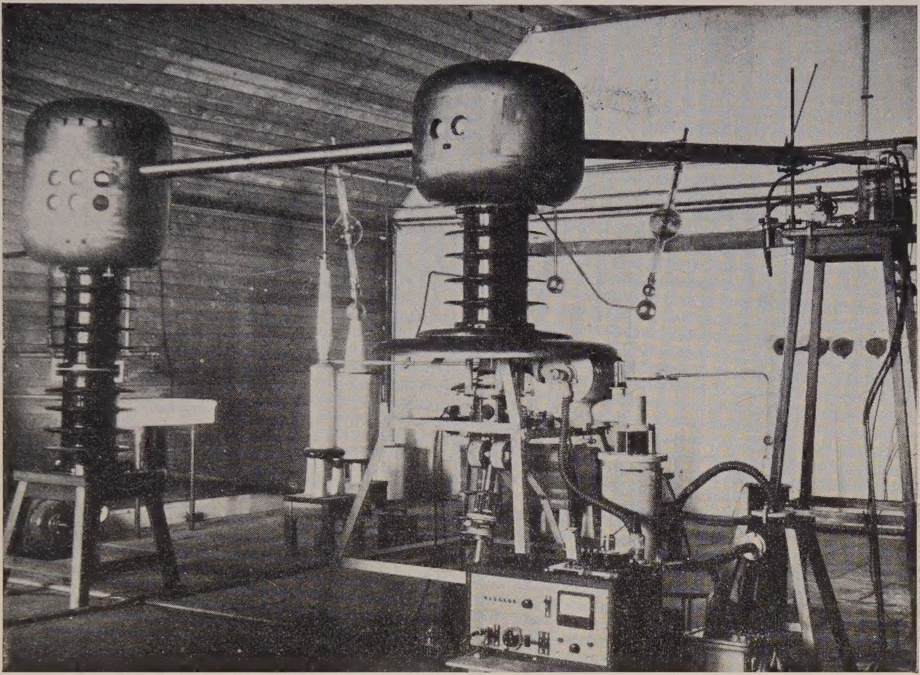

Fig. 1. Total view of the neutron generator.

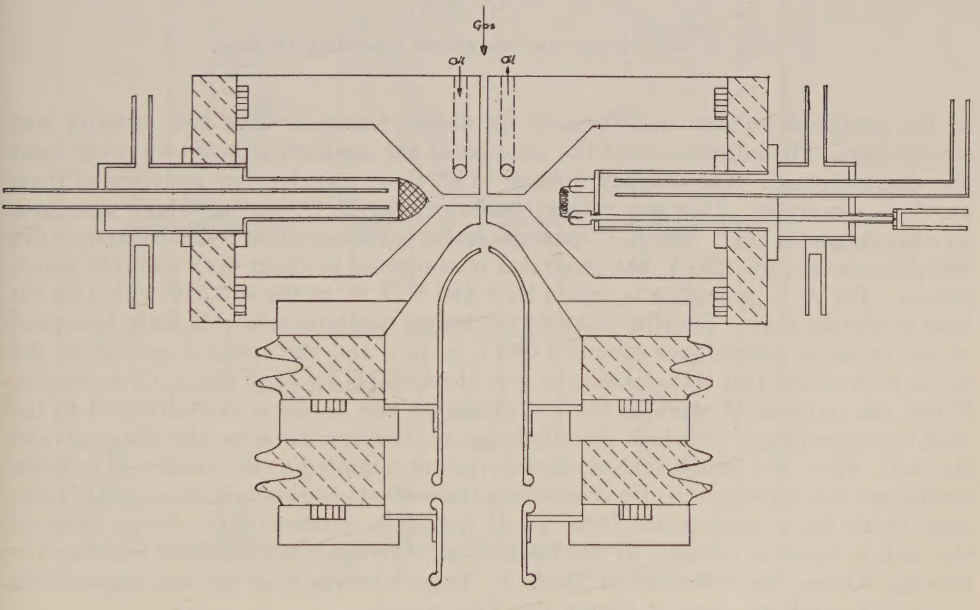

Fig. 2. Low-voltage arc ion source with a straight capillary.

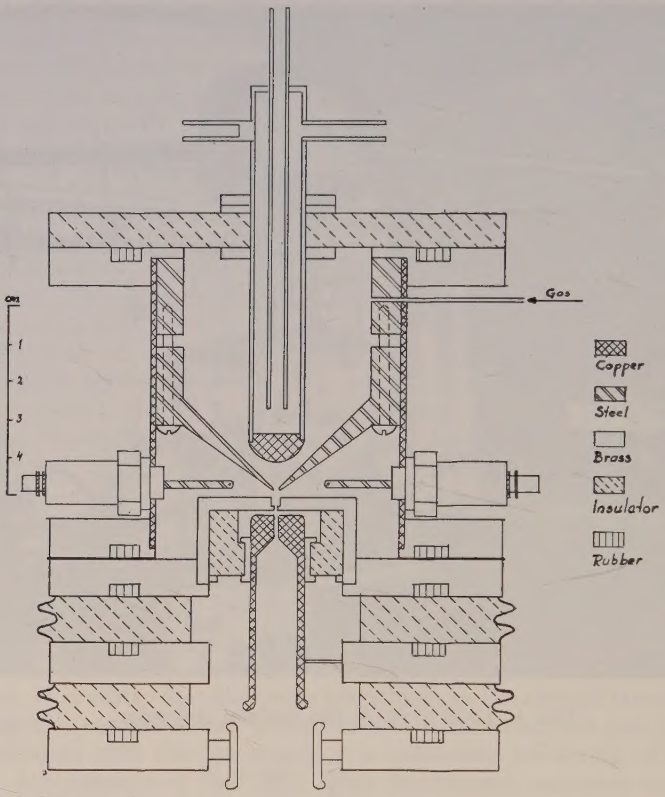

Fig. 3. Low-voltage arc ion source according to Zinn.

to the two high-voltage transformers, an autotransformer with two outputs was constructed. The adjustment of the position of the contacts is made by cords from the control panel. The primary voltage to all these transformers is delivered from an A. C. generator. This is a rotory convertor, the D. C.-part of which generates its own magnetic field. The A. C.-part generates a voltage of only 150 V, and as the transformers require 220 V, the generator is connected to them via a suitable transformer. The A. C. generator is driven by a 440 V D. C. motor of 3 HP with a 60 cm long insulating shaft. In order to avoid too strong oscillations in this shaft, the speed of the motor is rather slow (about 1 000 r. p. m.), and the speed is geared up 2.8 times with a cone belt transmission to give the suitable speed of the A. C. generator.

For the purpose of starting the arc discharge the anode is shortcircuited to the wall, in consequence of which the discharge commences between the filament and the wall. When the switch is then opened, the arc is ignited to the anode, if the other conditions are appropriate. By connecting the cathode to the wall via a great resistance (2 000 Ω), a more stable behavior of the arc is obtained, and the potential of the wall is fixed in relation to the electrodes. Average conditions for running the two ion sources are compiled in Table 1. Type 1 means here the ion source with a straight capillary, type 2 means the Zinn source.

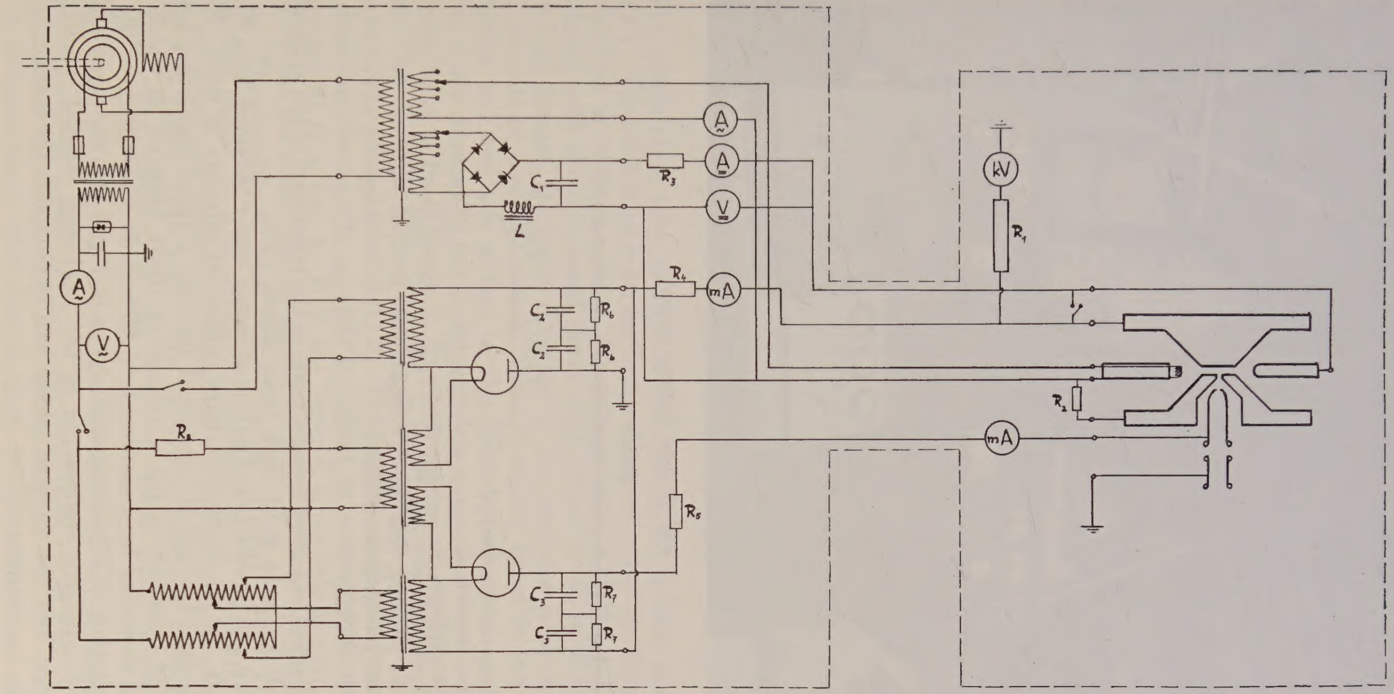

Fig. 4. Coupling scheme of the electrical equipment for running the ion source, which is visible to the right. The components to the left are enclosed within the other corona shield.

$R_1 = 20.3$ MΩ
$R_2 = 2$ kΩ
$R_3 = 120$ Ω
$R_4 = 100$ kΩ

$R_5 = 50$ kΩ
$R_6 = 5$ MΩ
$R_7 = 3$ MΩ
$R_8 = 400$ Ω

$C_1 = 32$ μF
$C_2 = C_3 = 1$ μF
$L = 0.5$ H, 4 Ω

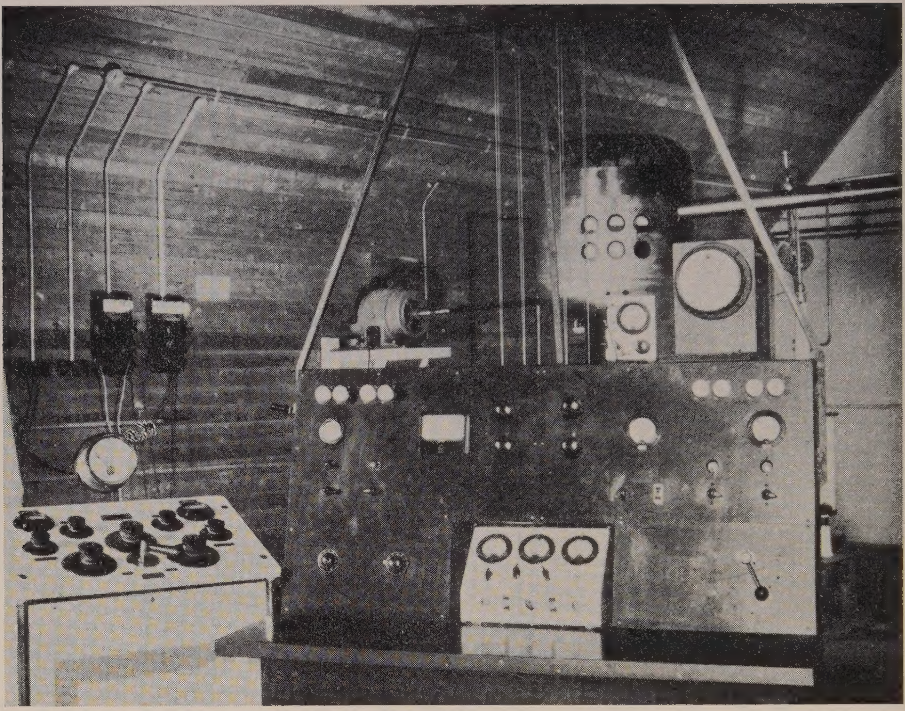

Fig. 5. The control panel.

Table 1

	Ion source	
	Type 1	Type 2
Filament current, A	8	8
Arc current, A	1.2	0.6
Arc voltage, V	70	70
Power consumption, W...	140	100
Gas pressure, mm Hg....	0.01—0.02	—
Gas consumption, µl/sec. .	15	8
Ion current, µA	10	80

The ion current is measured as a good focused beam in the lower part of the apparatus. The percentage of atomic ions is in both cases about 15 %.

The deuterium gas is produced by electrolysis of heavy water obtained from Norsk Hydro (99,77 % D_2O). As an electrolyte, pure potassium sulphate is used. From the electrolysis apparatus the gas is conducted through a speed-regulating needle valve to an evacuated reservoir having a volume of about 1 000 cc, in which the pressure of the gas is measured by a manometer. All remote controllings of the ion source are brought together on a control panel, shown in Fig. 5. On the same control panel are placed the auxiliary equipments of the analysing magnet, cooling-oil pump, vacuum pumps, and the vacuum gauge and instruments for measuring the high voltage and the ion current.

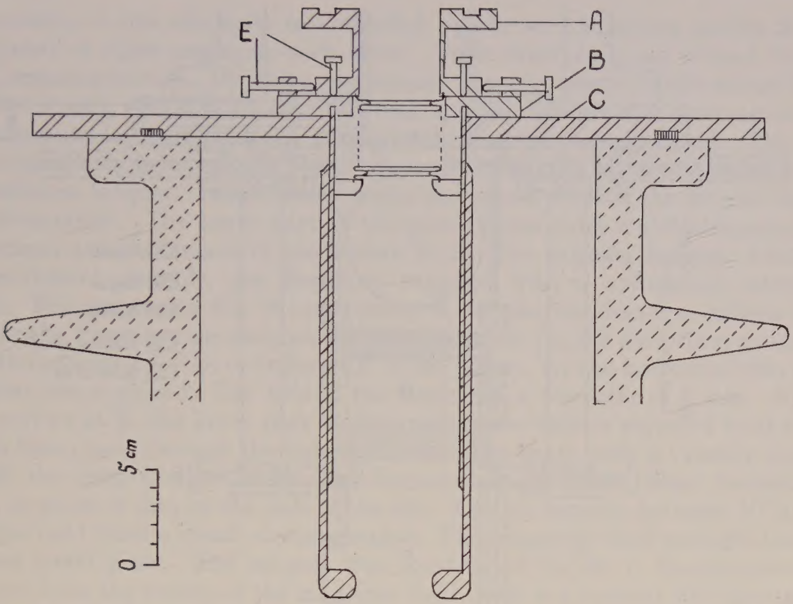

Fig. 6. The upper acceleration electrode.

The acceleration tube

The acceleration tube is built in one section for a max. accelerating voltage of 200 kV. The ion source is on the high voltage side, and the target on the earth side, shielded by an earthed screen. The arrangement is shown in Fig. 1. The porcelain insulator, with the upper and lower ends ground level, is 50 cm long and supplied with four flanges; the inside diameter of the insulator is 20 cm. The vacuum tight seal is made of a rubber gasket, which is tightly fitted to the plane surface of the insulator and lies in a groove of the affixed steel plate.

Fig. 6 is a drawing of the upper electrode in the acceleration tube. It is connected vacuum-tight to brass-flange A, on which the ion source with its prefocusing system rests. The electrode is fixed to a small brass-flange B which is fitted with a rubber gasket to the ground steel-plate C. The position of the ion source in relation to the acceleration electrode is possible to adjust by means of the two groups of screws which are at E in Fig. 6. With the latter it is possible to control the parallel movement of the ion source on the horisontal plane, and its inclination towards the same plane. The mobility is made possible by the sylphon bellows which connect the electrode and flange A. This device is mentioned by S. Eklund.[1] The electrode itself is of an adjustable length, the lower part being possible to shift within wide limits along the upper fixed part. The surface is carefully treated, crome-plated and polished. The acceleration gap is 3.1 cm when good focusing is obtained at all tensions.

The lower acceleration electrode is of the same construction as the upper. Its connection to the corresponding lower steel plate (A in Fig. 7) is however movable.

---

[1] S. Eklund, Ark. f. Mat. Astr. o. Fysik, Bd 33 A, N:o 14.

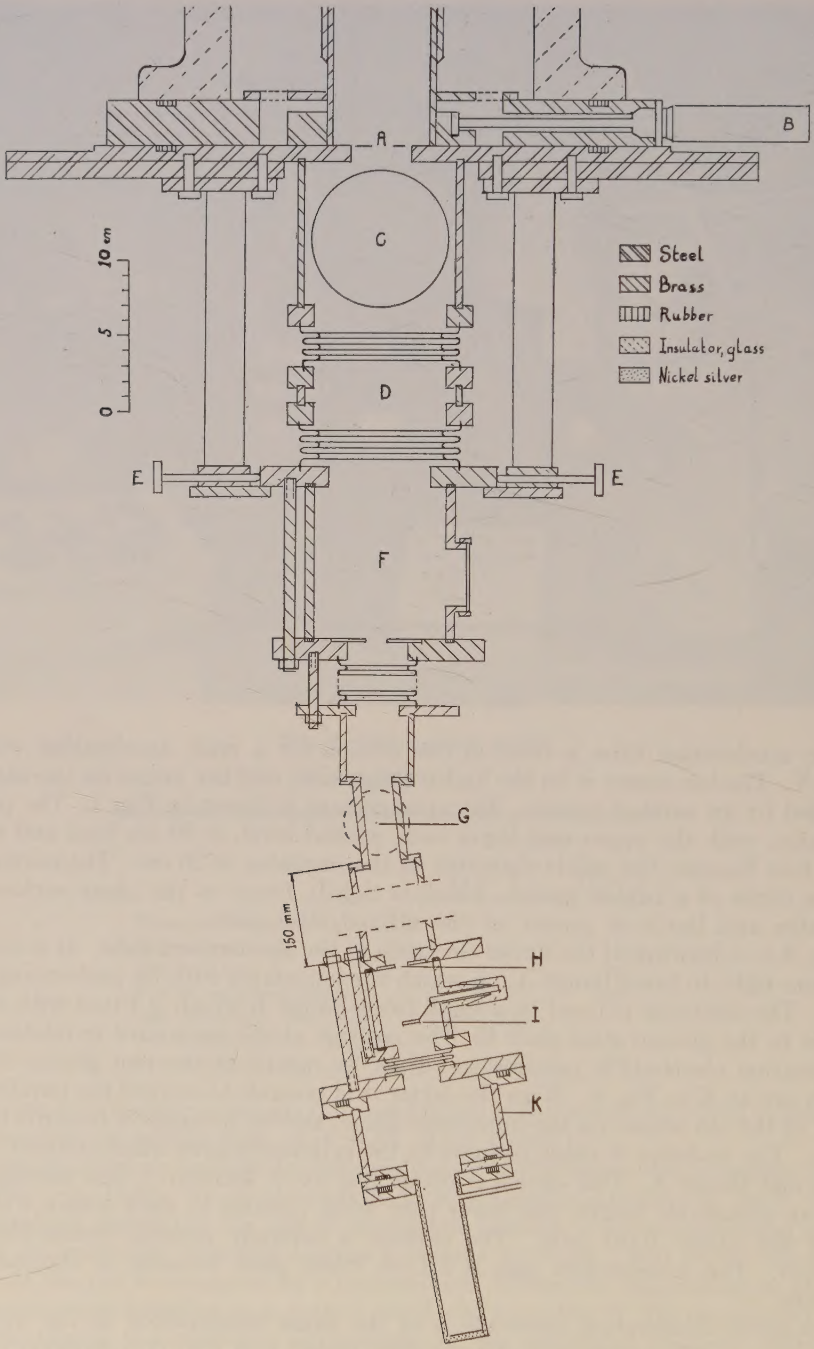

Fig. 7. The lower part of the acceleration tube.

The position of this electrode is controlled by the two adjusting screws B. These are located at right angles to each other. Their inner ends are shaped into small plates, running in ruts. By this arrangement, the movement is fully controlled with only two screws, which being supplied with sylphon bellows and nuts, are accessible from the outside. Steel plate A supports the earthed copper shield. This as well as the conductors are made of 1.5 mm copper sheeting, the surface of which is treated with cellulose lacquer. Immediately under the shield there is the 90 mm wide tube C for evacuation. The lower part of the acceleration tube is shiftable parallel with the vertical axis by means of the screws at E. The sylphon bellows, which make this movement possible, are therefore supplied with a cylindrical intermediate section. For measuring the vacuum there is, on the one hand, a carbon-filament lamp for the Pirani gauge, and, on the other, a triode for the ionization gauge, which are both connected to the cylinder at F in the figure. At the bottom of this cylinder a circular iris is placed. The hole of the latter has a diameter of 8 mm. By means of the screws at E, the lower part of the acceleration tube is adjusted so as to let the focused beam pass through the hole of the iris. The beam path is visually observable through the glass window at F. The diameter of the beam, when focused on the target, is about 3 mm in the hole of the iris. Thei on beam is deviated 10° at G by a magnetic field from a small electro-magnet. The magnetic field strength has a max. of about 9 000 gauss. The magnet was constructed by Mr I. BARTHOLDSSON. At H, 18 cm from the centre of the magnetic field there is a circular slit, through which the separated ion beam passes. The focusing of this beam may be observed on quartz plate I, located in the centre of a glass cylinder. The quartz plate is fixed to a standard grinding of glass which is fitted vacuum-tight to the corresponding grinding of the cylinder, and it may therefore easily be brought into the path of the beam or turned aside from it. Under this glass cylinder is one of brass K, which is connected to the upper part by insulating rods. This part is given a potential of —100 V during the measuring of the ion current. The target is screwed tight on to cylinder K, but electrically separated from it by an insulating plate of perspex. This lowest part, which is cooled by liquid air, is made of nickel silver. A narrow brass tube opens out into this part, connecting it with a glass bulb containing heavy water.

Evacuation

The capillary arc ion source consumes about 15μl/sec. of deuterium at 760 mm Hg, i.e. a leakage into the high vacuum side of 114 l/sec. at a pressure of 10^{-4} mm Hg. In order to retain the acceleration tube at such a pressure fast vacuum-pumps are required. The applied pump system consists of a rotory pump and two diffusion pumps in series. The last one is connected to the acceleration tube via a cooling trap and a valve-cap. It is an oil diffusion pump made here at the institute and having a pumping speed of 250 l/sec. at 10^{-4} mm Hg. The second is a so-called Booster pump. The system is built in such a way as to make it possible to fill up the acceleration tube with air of atmospheric pressure and then to evacuate it by the rotory pump without cutting off the current to the diffusion pumps. The pressure is measured by a combined Pirani- and ionization gauge.[1] The whole instrument is fed from 220 V A. C. The acceleration tube is evacuated to 10^{-5} mm Hg, but when running it has the pressure of 10.10^{-5}–20.10^{-5} mm Hg. It has been proved

---

[1] S. v. FRIESEN, Ark. f. Mat. Astr. o. Fysik. Bd 27 B, N:o 11.

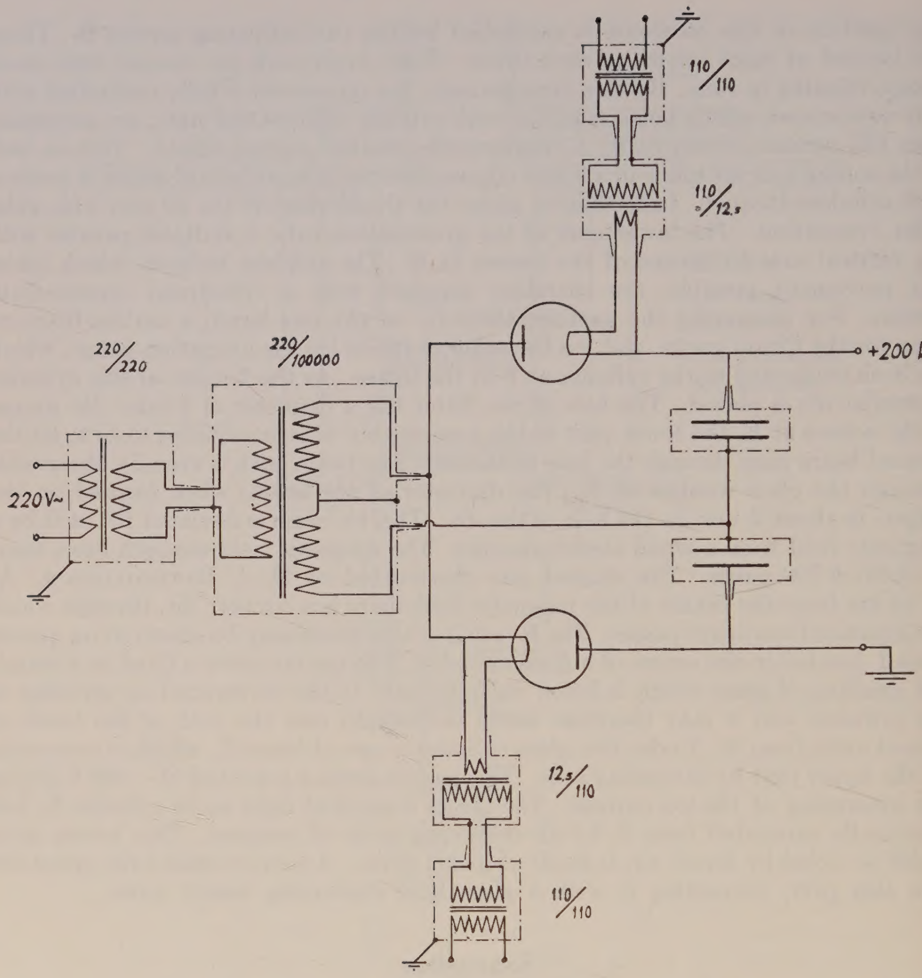

Fig. 8. Coupling scheme of the high voltage installation.

that the pressure in the high vacuum tube is a sufficiently sensitive measure of the gas pressure of the ion source. It is therefore possible to adjust the needle valve of the ion source to a suitable value by reading the deflection of the ionization gauge.

The high-tension installation

Fig. 8 is a coupling scheme of the voltage-doubler high tension aggregate. The centre of the high voltage transformer is earthed so that the aggregate gives +100 and —100 kV.[1] So as to be able to connect the whole available voltage of 200 kV to the acceleration tube, the aggregate was improved in the following way. The high-voltage and filament transformers have been insulated from earth and are now fed via insulating transformers from a 220 V power supply. These new transformers are also shown in the figure.

---

[1] E. Ingelstam, Nova Acta Regia Soc. Sci Upsaliensis, Ser IV, vol. 10, N:o 5.

For measuring the high voltage, there is an oil-cooled high-ohmic resistance, which was constructed by Mr I. BARTHOLDSSON. It consists of 110 oil-constant carbon-layer resistances of nominally 4 MΩ. The total resistance was measured by the volt-ampère-method, in doing which the current was measured with a carefully calibrated galvanometer, the applied voltage being 300 V. The total resistance amounts to 476 MΩ, by 20° C. The error in the value is estimated to 0.5 %, but repeated measurements coincide within 1 ‰. The temperature coefficient was measured to -6.10^{-4} deg.$^{-1}$ in the interval 15°–50° C.

Ripple was determined by an oscillograph connected to a part of the measuring resistance. The ripple-percentage is shown in Table 2.

Table 2

Voltage kV	Ripple %
50	0.68
100	0.65
200	0.60

The characteristics of the neutron generator and some measurements will be reported in a following paper.

To the Head of the Physical Institute, Professor AXEL E. LINDH, I wish to express my sincere thanks for his great generosity in connection with this work, and for the confidence he has shown in me. He has from the beginning taken active part in the construction work, and then always facilitated the proceeding of the work in every way.

Dr. S. EKLUND kindly shared his great experience at the beginning of the work with the neutron generator, and I should like to express my thanks to him as well as to Professor P. OHLIN for the interest he has shown in the work and much valuable advice. Fil. kand. I. BARTHOLDSSON has rendered me valuable assistance during the final phase of the work, and I wish to express my gratitude to him.

The Physical Institute, University of Uppsala, November, 1949.

Tryckt den 8 augusti 1950

Uppsala 1950. Almqvist & Wiksells Boktryckeri AB